50 years University of Mining and Geology “St. Ivan Rilski”
Annual, vol. 46, part II, Mining and Mineral Processing, Sofia, 2003, pp.5-10

VALUATION OF THE POSSIBILITIES FOR CHOOSING OF EFFECTIVE METHOD OF DEVELOPMENT FOR ORE BODIES WITH COMPLICATED MORPHOLOGICAL CHARACTERISTIC

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ABSTRACT
In development of ore bodies represented as separate geological blocks - poles, originate the problem with choosing of optimal method of development, when part of ore body is above ventilation horizon, respectively part of ore body remains below haulage horizon. In such cases is not expedience performance of full complex developing and cutting works, typical of the created mining technology because of limited volume of reserves in that zone. Object function is created, on the basis of that can be compared different variants of development and cutting of block with such complex morphological fact. Alternative graph is created, giving possibility for generating great number of variants, from among that should look for optimal.
Key words: ore, vain, minerals, mine field, development, graph.

INTRODUCTION

The design and practical implementation of mine fields developing is carried out under conditions of least reliability of information about the environment, when the mine field is determined in project stage and data are gathered during the process of driving prospecting workings. Often this information is based on data in driving or exploiting of mine workings in the mine field. This gives possibility to set up of more precise and more complete information for the space situation of the ore bodies in earth’s womb.

The term of exploitation of the basic development and cutting workings often corresponds to the period of development of the mine field and every driving of needless workings in not paying ore zones has got serious economic consequences. This is showed in significant increasing of the investments for developing and cutting works, not retrieve of the investments subsequently.

BASE ON THE PROBLEM

When developing ore deposits the problem is further complicated by at least three additional, but at the same time essential factors published by G. Mihaylov and G. Georgiev (2002):

- Very often ore veins have got uneven distribution of useful components, they are represented by separate ore poles, which further on for convenience will be called *geological blocks*;
- The separate geological blocks in the ore veins have got clearly identifiable inclination, which in depth has considerable influence on the dimensions and boundaries of the mine field, i. e. inclination influences the topology of the network of extraction workings for the opening and preparation of the levels;
- The thickness of ore veins (geological blocks) is uneven, which means that the amount of loads corresponding to the reserves in the separate blocks on the separate levels will be different.

In this way premises are created for the development of a general algorithm based on multivariant approach for the choice of a technical solution and valuation of the variants for the developing of the mine field, based on the three-dimensional formulation of the problem. A reference coordinate system is introduced, oriented in such a way that the whole mine field is situated in the positive octant. The (y) axis coincides with the ore vein’s strike line, while the (x) axis is oriented crosswise to the strike line, i.e. along the way of dipping.

When the geological blocks’ coordinates on the separate levels are known it is possible to calculate the geometrical dimensions, the amount, the productivity and the location on the separate levels by means of three angles (fig.1):

- The angle of dip α of the vein or the geological block in the plane 0xz, α varying on the interval $0 \le \alpha \le 180°$;

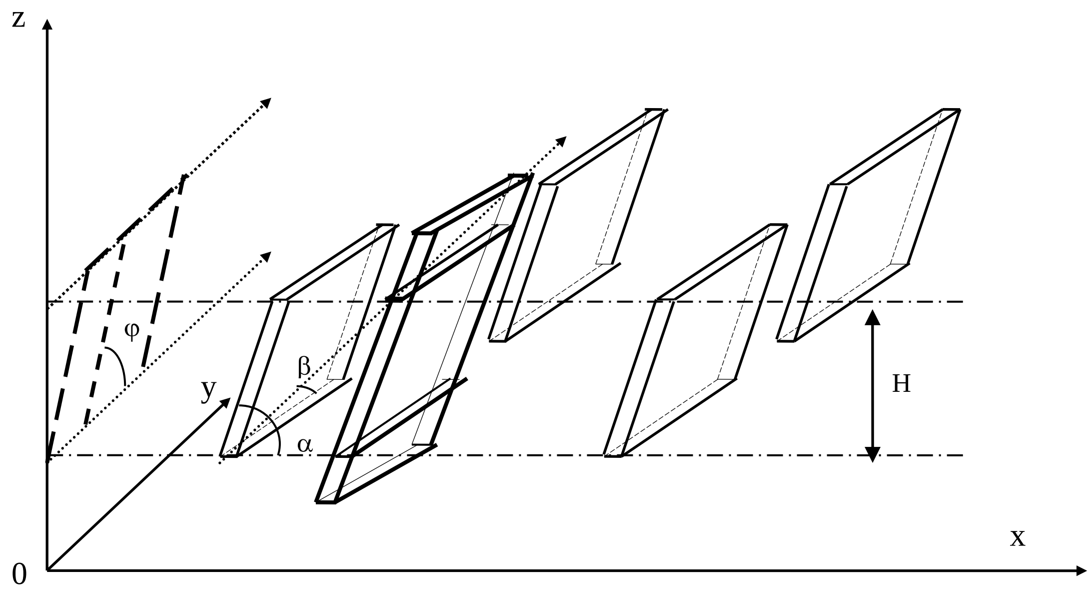

Figure 1. 3D base on the problem

- Angle of inclination φ of the geological block on the separate levels in the plane 0yz, φ varying on the interval $0 \le \varphi \le 180°$;

- The angle of azimuth β of the geological block on the separate levels in the plane 0xy, β varying on the interval $0 \le \beta \le 360°$.

The calculation of parameters such as geometrical dimensions, amount, productivity, takes place once the angles α, β, φ have been determined by means of the geological blocks' coordinates on the separate levels.

The problem thus formulated necessitates the introduction of triple indexation - i, j, k where:

i = 1..n – the index showing the sequential number of the geological blocks (poles), located on the level, and situated along the ore veins' strike line;

j =1..m – the index showing the location of the following vein, determined crosswise to the strike line;

k =1..t – the index showing the level's sequential number within the mine field.

In this case, when the stope block's geometry is predetermined (length L_{bl} and height $H_{bl} = H_l$, where H_l is the level's height) it is possible to calculate the amount of reserves, respectively amount of loads Q[ijk], to be transported to the surface and then to the consumer.

That base on the problem is possible only in this way, when geological pole (block) not has got non ore zones along way of dipping (whole height of level).

When geological pole (block) has got interrupting along way of dipping in limit of level or the ore zone goes up from haulage (ventilation) horizon reach some level, which located between both horizons forming one mine level and subsequently the ore zone is non ore to ventilation (haulage) horizon. Than is necessary introduction on fourth index (d):

d =1,2, ... p – the index showing the sequential number of the geological blocks (poles), and situated along the ore veins' dip line;

The problem is complicated after introduction on fourth index, but on the other hand more complexly solution is obtained giving variability of the form of the ore zone along the ore veins' dip line. New index (d) characterizing naturally datum of the deposits is different from number of the levels. New index (d) in the mine field can be in three dependence d = k, d > k и d < k. One of very often variants is in d = 1, when the ore zone is without interruption along the whole dip line. The ore zone is intersecting by ventilation and haulage horizons on levels. Very often, however, this condition is not performed than d > 1.

For facility's sake when we look at surface 0xz, instead three-dimension (3D) base on the problem (fig.1), from where we can see the scheme of the location of the ore body represented by fig. 2

In the boundary of one level between haulage and ventilation horizons can be formed from several ore zones. Of course, this precise making of contour of the ore zones can be performed in the driving of developing workings, when the mine field is in stage of development, and not making of contour which can be performed in process of driving prospecting works.

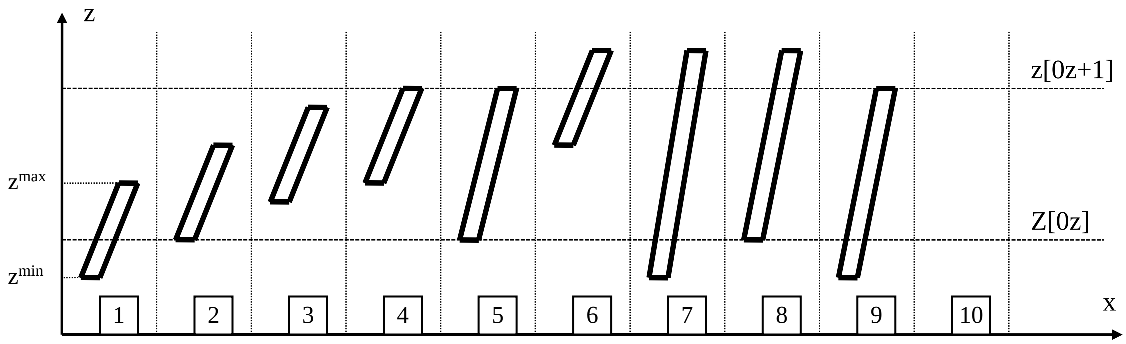

Figure 2. Location of the ore body in boundary of level

The situation of the ore body in the limit of level is shown in fig. 2. When we are look at Oxz, forming cross-section of the ore body can be make some marks:

- z[0z+1] is the axis of crosscut situated on ventilation horizon forming upper boundary of level.
- z[0z] is the axis of crosscut situated on haulage horizon forming bottom boundary of level.
- z^{max} – the maximum coordinate forming upper boundary of [i, j, d]th geological pole (block);
- z^{min} – the minimum coordinate forming bottom boundary of [i, j, d]th geological pole (block);

Last two are shown in fig.2 only in this case for variant 1, but in the other cases is on the analogy of all the rest variants.

MATHEMATICAL FORMULATION OF THE PROBLEM

Calculating the amount mineral body located in the ore zone between ventilation and haulage horizon Q[ijk]. For that purpose is necessary preliminary to be calculated the amount in a geological pole (block) – Q[ijd] in that complicated morphology of the ore bodies. This is represented by the formulas describing different variants:

- Variant 1:

$$Q[ijk] = (Q[ijd].Z_p[ijk]) / Z_o[ijd], t \quad (1)$$

where:

$Z_p[ijk]$ – the height along the (z) axis fig.2, located between maximum coordinate of the ore body and the axis of haulage crosscut and remaining in the boundary of level:

$$Z_p[ijk] = z^{max}[ijd] - z[0z], m; \quad (2)$$

$Z_o[ijd]$ – the height of ore body as difference between the maximum and minimum coordinate in each [ijd]th geological pole (block):

$$Z_o[ijd] = z^{max}[ijd] - z^{min}[ijd], m; \quad (3)$$

Q[ijd] – preliminary calculated amount ore mass in each [ijd]th geological pole (block),t:

- Variants 2,3,4 and 5:

$$Q[ijk] = Q[ijd], t. \quad (4)$$

- Variant 6:

$$Q[ijk] = (Q[ijd].Z_{pk}[ijk]) / Z_o[ijd], t \quad (5)$$

where:

$Z_{pk}[ijk]$ – the height along the (z) axis fig.2, located between the axis of ventilation crosscut and minimum coordinate of the ore body and remaining in the boundary of level:

$$Z_{pk}[ijk] = z[0z+1] - z^{min}[ijd], m; \quad (6)$$

$Z_o[ijd]$ – the height of ore body as difference between the maximum and minimum coordinate in each [ijd]th geological pole (block):

$$Z_o[ijd] = z^{max}[ijd] - z^{min}[ijd], m; \quad (7)$$

Q[ijd] – preliminary calculated amount ore mass in each [ijd]th geological pole (block),t:

- Variants 7,8 and 9:

$$Q[ijk] = (Q[ijd].Z_e[ijk]) / Z_o[ijd], t \quad (8)$$

where:

$Z_e[ijk]$ – vertical height of level, m:

$$Z_e[ijk] = z[0z+1] - z[0z], m; \quad (9)$$

$Z_o[ijd]$ – the height of ore body as difference between the maximum and minimum coordinate in each [ijd]th geological pole (block):

$$Z_o[ijd] = z^{max}[ijd] - z^{min}[ijd], m; \quad (10)$$

Q[ijd] – preliminary calculated amount ore mass in each [ijd]th geological pole (block),t:

- Variant 10 – not has got minerals in level. That variant can be obtained in large interruption of the ore zone along the ore veins' dip line. That can be obtained when ventilation and haulage horizons forming level not intersect [I, j, d] ore body.

Creating of an object function in the developing and cutting in each blocks in the mine field:

$$F = \sum_{l=1}^{r} C_d L_{d(l)} + \sum_{l=1}^{r} C_c L_{c(l)} \rightarrow \min, \quad \$ \qquad (11)$$

where:
C_d – the prime cost of one linear meter (1m) developing working, \$/m;
$L_{d(l)}$ – the general length of all developing mine workings in the mine field, m;
C_c – the prime cost of one linear meter (1m) cutting working, \$/m;
$L_{c(l)}$ – the general length of all cutting mine workings in the mine field, m;
l = 1,2, … , r – shows number of the variants depending on the indexes [i, j, k].
Existing the following relation between them:

$$r = n.m.t \qquad (12)$$

That object function shows the investments necessary to the developing and the cutting of the mine field. For that purpose to be expedience development of the deposit the object function must be minimum:

The investment for developing and cutting in each one of the extraction geological blocks (i), in each ore vein (j), forming from ventilation and haulage horizons in level (k) and it is expressed by formula:

$$F[i, j, k] = C_d.L_d[i, j, k] + C_c.L_c[i, j, k], \quad \$; \qquad (13)$$

where:
L_d[i, j, k] – length of all developing mine workings in the boundary of [i, j, k]th extraction block, m;
L_c[i, j, k] – length of all cutting mine workings in the boundary of [i, j, k]th extraction block, m;

The financial incomes for each one of the extraction geological blocks (i), in each ore vein (j), in each level (k) and it is expressed by formula:

$$Inc[i, j, k] = Q[i, j, k].W, \quad \$; \qquad (14)$$

where:
Q[i, j, k] – the calculating amount mineral located between ventilation and haulage horizons in each one of the variants shown by fig.2.
W – extracting value obtained through formula published by V. Shestakov, A. Dulin etc. (1984):

$$W = 0{,}01\sum_{1}^{n} c(1-S)\varepsilon R, \quad \$/t \qquad (15)$$

where:
c – the substance of mineral components (metal substance) in ore, %;
S – the dilution of ore in extraction;
ε - the extracting of useful mineral components in mineral processing of ore mass;
R – the price of 1t metal, \$;
n – number of mineral components in ore.

The value of the ore is formed through containing in the ore useful mineral components – through their amount, quality and market price. When the ore contains one component, as for example the iron ore, more value is that, which is with higher metal content. The value of polymetal ore is represented as sum through the value of the metals which contains published by Dr. Steffanov (1993).

The value of the ore influence as over choice of method of mining and technology of development, similarly in the opening and the developing of the mine field. In value ore can be applied expensive technologies and method of mining, if it is insure minimum losses of ore in extraction. As well, can be prepared and cut geological blocks with amount less located on the level. In ore with little value permit cheap methods of opening, developing and extraction and it permit increased losses too.

The profitableness of the developing in each [i, j, k] extraction block is defined as difference between Inc[i, j, k] and F[i, j, k] with giving an account of extraction worth of the ore. When the difference is positively, the preparing and the development of separate extraction block is economic expedience. The profitableness, defined according to extraction value of the ore, still must apprehend as relatively, as in many cases must not evaluate the metal as material, and the last made product.

CREATING OF AN ALTERNATIVE GRAPH

According to thereby made 10 variants about situation of the ore body in the boundary of level, we could see from fig.2, is created general alternative graph shown in fig.3.

S_n – beginning of alternative graph;
S_k – end of alternative graph;

- Level A – depending on number of the ore body located in the boundary of level;
1 – one ore body or part of ore body;
2 – many ore bodies, where the amount ore mass located on level is calculated as sum;
3 – There is not ore body in level.

- Level B – depending on the location of upper contour of [i,j,d] $^{-th}$ ore body z^{max} toward upper boundary of level, in this case ventilation horizon or the axis of crosscut located on ventilation horizon - z[0z+1] shown in fig.2:

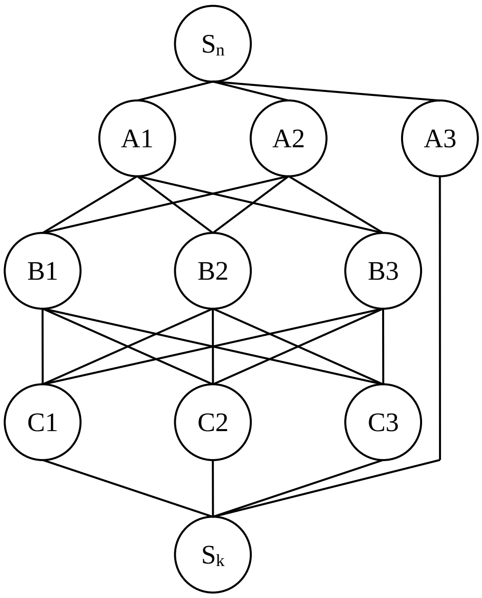

Figure 3. General alternative graph

1 – upper contour remains outside on level formed through ventilation and haulage horizon, and the axis of crosscut situated on ventilation horizon (fig.2) intersect the ore body;
2 – upper contour osculate ventilation horizon (the boundary of level) or the axis of crosscut situated on ventilation horizon (fig.2);
3 – upper contour remains inside between ventilation and haulage horizon (in the boundary of level) and the axis of crosscut situated on ventilation horizon (fig.2) not intersect the ore body.

- Level C – depending on the location of bottom contour of [i,j,d] $^{-th}$ ore body z^{max} toward bottom boundary of level, in this case haulage horizon or the axis of crosscut located on haulage horizon - z[0z] shown in fig.2:

1 – bottom contour remains outside on level formed through ventilation and haulage horizon, and the axis of crosscut situated on haulage horizon (fig.2) intersect the ore body;
2 – bottom contour osculate haulage horizon (the boundary of level) or the axis of crosscut situated on haulage horizon (fig.2);
3 – bottom contour remains inside between ventilation and haulage horizon (in the boundary of level) and the axis of crosscut situated on haulage horizon (fig.2) not intersect the re body.

The maximum common number of variants according to alternative graph can be shown by formula:

$$V = 10.n.m.t, \quad бр. \qquad (16)$$

In this way a general problem is formed, the solution to which should be regarded as an example of the use of a comprehensive approach in the present day computer technology used in mining.

THE RISK OF THE INVESTMENT

According to Gotch, Zantrop and Eggert the risk of investments in field of development of mineral raw material is: "The risk in the true sense of the word is as measure of the rate of variability of the possible financial incomes and expense. Investments with low risk have got low variability of the possible financial incomes in comparison with that with high risk. The future incomes and expense, connected with investment for development of mineral deposit, are not sure, because is impossible the factors, which define them to be reliable well - known in the moment of investing process" published by M. Yordanov (1996).

The balance of incomes and expense of given business initiative is the extremely, solving factor in claim of solution for her realization. The reporting on the stability trend to drop of investments in the mining industry in worldwide importance especially actual are the efforts of some countries and governments to offer in most attractive project mineral raw material basis, published by M. Yordanov (1998).

The risk of investing is in a direct ratio of measure of the expectation a clear profit from the investment i.e. bigger risk – bigger clear profit, and of the other side – less risk less clear profit. That is important with same power for the investments in mining industry.

The risk of investing is provoked of factors of geological substance – incorrectly calculated (or not confirmed) reserves of ore and metal, from geoeconomic – changing of the price of an end produced product (metal) and political and macro economic – changing of law.

The first group risks is most often met and has got biggest significance because of the fatally consequences in not confirmed of the calculating reserves of ore and metal. Series of financial losses in a number of gold extraction and other companies in Australia, USA and Canada in the end during the past century are connected mainly with such risks. In the not confirmed reserves of ore and metal, which is under condition thoroughly of two group factors: applying of old procedures for example the method of geological cross-section and blocks for deposits with extremely an not even distribution of useful component (gold, silver etc.). As well, incorrect using of geostatistic methods and technologies.

The second group risks is connected with the changing of price of end product (metal). The changing of prices influence in significant rate over the extremely economic results. For example of that are the sudden changing of the price in copper during the past two years.

The third group risks is connected with the changing of law. That changing put under financial success in anyone investment project of large and often not predicted risk.

CONCLUSION

Thereby made evaluation of the variants for effective method of developing of the ore bodies with complicated morphological characteristic, is clearly, that in some of the cases is not expedience performing of full complex of developing and cutting works, typical of given extraction technology for ores with low value or limited amount of the reserves in that zone. The created object function will has minimum, when is not performed full complex of developing and cutting works, in not paying ore zones. The using of that complicated variant approach based on creating alternative graph can be owing to the present computer technologies in mining.

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Recommended for publication by Department of Underground mining , Faculty of Mining Technology